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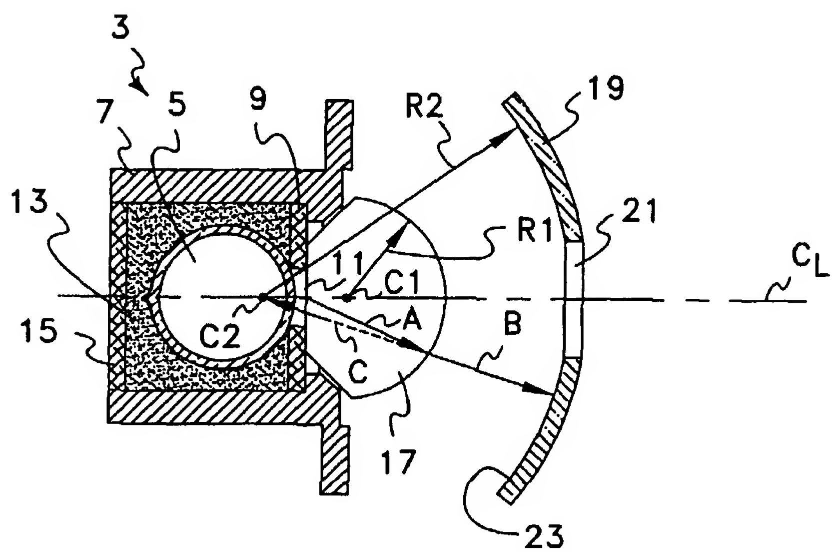
(54) Title: LAMP APPARATUS AND METHOD FOR EFFECTIVELY UTILIZING LIGHT FROM AN APERTURE LAMP



(57) Abstract: Various lamp systems are disclosed which effectively utilize light from an aperture lamp. Lamp systems are respectively configured to perform various types of light recapture including etendue recycling, polarization recycling, and/or color recycling. Various novel optical elements are disclosed including an electrodeless light bulb with an integral lens, a molded quartz ball lens with an integral flange, a molded quartz CPC with an integral flange, a truncated CPC, and a segmented CPC. Various novel optical systems are disclosed including systems which perform angle selection and/or etendue selection.

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LAMP APPARATUS AND METHOD FOR EFFECTIVELY UTILIZING LIGHT FROM AN APERTURE LAMP

Certain inventions described herein were made with Government support under Contract No. DE-FC26-99FT40635 awarded by the Department of Energy. The Government has certain rights in those inventions.

BACKGROUND

1. Field of the Invention

In general, the various aspects of the present inventions relate to lamp systems which beneficially utilize light from aperture lamps. Certain aspects relate to novel structures configured to reflect some of the light which exits the aperture back into the aperture for absorption and re-emission by the lamp plasma.

2. Related Art

In general, the present invention relates to the type of lamps disclosed in U.S. Patent No. 5,773,918 and U.S. Patent No. 5,903,091, each of which is herein incorporated by reference in its entirety. Each of the '918 and '091 patents discloses various lamp structures for making beneficial use of waste light.

SUMMARY

Many of the inventions described herein beneficially utilize light from the lamps described in co-pending PCT application no. PCT/US00/16302, filed June 29, 2000, and PCT Publication WO 99/36940, each of which is herein incorporated by reference in its entirety.

According to one aspect of the invention, a lamp system includes an envelope containing a fill capable of light recycling; and an optical element spaced from the envelope which is configured to reflect light emitted from the envelope outside of a desired angle back into the envelope for recycling by the fill while allowing light within the desired angle to pass, wherein the light output within the desired angle is higher as compared to the light output in the absence of the optical element, and

wherein the desired angle is selected in accordance with the uniformity and angular distribution of light from the envelope.

According to another aspect of the invention, a lamp system includes an envelope containing a fill capable of light recycling; and a high temperature wire grid polarizer closely spaced to the envelope which is configured to reflect light of an undesired polarity back into the envelope for recycling by the fill while allowing light of the desired polarity to pass, wherein the wire grid polarizer is capable of withstanding an operating temperature of at least about 400° C.

According to another aspect of the invention, a lamp system includes an envelope containing a fill capable of light recycling; an optical element which defines an aperture corresponding to a desired angle with respect to the envelope; and a high temperature wire grid polarizer closely spaced to the optical element in the area of the optical element aperture, wherein the optical element is spaced from the envelope and is configured to reflect light outside of the desired angle back into the envelope for recycling by the fill and wherein the polarizer is configured to reflect light of an undesired polarity back into the envelope for recycling by the fill, whereby the light exiting the lamp system is within a desired acceptance angle and of a desired polarity, and wherein the light output is higher as compared to the light output in the absence of the optical element and polarizer. For example, the polarizer is disposed in the aperture defined by the optical element. In another example, the polarizer is planar and the system further includes a lens disposed between the polarizer and the bulb, wherein the lens is adapted to increase the amount of light reflected back into the envelope by the polarizer.

According to another aspect of the invention, an optical apparatus includes a plurality of optical fibers which define an interstitial space therebetween; and reflective material selectively disposed over the interstitial space.

According to another aspect of the invention, a method of making a mask on an optical apparatus which includes a plurality of optical fibers which define an interstitial space therebetween, the method includes disposing photo-active material over both the fibers and the interstitial space on one end of the optical apparatus; illuminating the other end of the optical apparatus with suitable light to photo-activate

the photo-active material; and removing either the activated or the un-activated material to provide the desired mask.

According to another aspect of the invention, a lamp system, includes an envelope containing a fill capable of recycling light; and a fiber optic bundle having a plurality of optical fibers which define an interstitial space therebetween and reflective material selectively disposed over the interstitial space, wherein the reflective material reflects at least some light which does not enter the optical fibers back into the envelope for recycling by the fill.

According to another aspect of the invention, a lamp system, includes an envelope containing a fill capable of light recycling; a reflective material encasing the envelope except in the region of a light emitting aperture; and an optical element aligned with light exiting the envelope and closely spaced to the envelope, wherein the optical element bears an anti-reflection coating configured to transmit light within a desired angular distribution and to reflect light outside of the desired angular distribution back to the envelope for recycling.

According to another aspect of the invention, a lamp system, includes an envelope containing a fill capable of light recycling; and an optical element aligned with light exiting the envelope, wherein the optical element includes a reflective structure spaced from the envelope, wherein the reflective structure defines a plurality of light emitting apertures, and wherein the optical element and reflective structure together are configured to direct light which does not pass through the plurality of light emitting apertures back to the envelope for recycling.

According to another aspect of the invention, a lamp system, includes an envelope encased in reflective ceramic except in the region of a light emitting aperture; and an optical element in close proximity to the aperture along an optical axis, wherein the area of the aperture increases in a direction along the optical axis away from the bulb 133, thereby allowing greater optical access to the bulb relatively closer positioning of the optical element as compared to an aperture of uniform area.

According to another aspect of the invention, a lamp system, includes an envelope encased in reflective ceramic except in the region of a first aperture; and a hollow optical element positioned with an input end against the encased envelope, wherein a surface of the input end contacting the encased envelope is reflective,

and wherein the input end defines a second aperture and an inside perimeter of the second aperture is inside of a perimeter of the first aperture such that the second aperture defines the light emitting aperture for the envelope.

According to another aspect of the invention, a lamp system, includes an envelope; a light rod integrally joined to the envelope; and a reflective ceramic material covering the envelope except in the region where the light rod is joined to the envelope, wherein the reflecting ceramic material is beveled near the junction of the envelope and the light rod to avoid scattering light which enters the rod.

According to another aspect of the invention, an electrodeless lamp bulb, includes a body portion; and an optics portions integrally joined to the body portion, wherein the body portion and the optics portions together form a sealed interior volume. For example, the optics portion comprises a truncated ball lens defining a flat entrance face inside the sealed interior volume of the bulb.

According to another aspect of the invention, a high temperature, monolithic optical element, includes an optics portion; and a positioning portion joined with the optics portion, wherein the positioning portion is adapted to not interfere with the operation of the optics portion and wherein the two portions are made of one-piece construction of a suitable material to withstand an operating temperature of at least 400° C. For example. the optics portion comprises a truncated ball lens, the positioning portion a flange on the entrance face of the ball lens, and the two portions are made from molded quartz. In another example, the optics portion comprises a CPC, the positioning portion is a flange on the exit face of the CPC, and the two portions are made from molded quartz.

According to another aspect of the invention, an optical element includes a plurality of truncated cone sections with angled steps having a straight cross section and adapted to approximate a curved cross section.

According to another aspect of the invention, an optical element includes a round input face and an output face which is truncated from a round shape to a relatively more rectangular face with four sides which are substantially perpendicular to the output face.

According to another aspect of the invention, an optical element includes four segments joined to each other along respective edges, wherein each segment

corresponds to a minor portion of a CPC and maintains the curve of a CPC to provide a desired angular transformation while providing a relatively more rectangular output.

According to another aspect of the invention, an optical system, includes an input iris and an output iris aligned along an optical axis and configured to constrain light passing therethrough to a desired angular extent; and an optical element positioned proximate to the output iris and adapted to bend edge rays inward with respect to the optical axis while leaving interior rays unaltered.

According to another aspect of the invention, a lamp system, includes an envelope containing a fill capable of recycling and covered by reflective ceramic material except in the region of a first aperture; and a reflector spaced from the envelope and defining a second aperture aligned with the first aperture along an optical axis, the reflector being adapted to reflect light from the first aperture, striking the reflector outside of the area of the second aperture, back into the first aperture for recycling, wherein a distance of the second aperture from the first aperture and a relative size of the second aperture with respect to the first aperture are selected in accordance with a target etendue.

According to another aspect of the invention, a lamp system, includes an envelope containing a fill capable of recycling and covered by reflective ceramic material except in the region of an aperture; an angle selecting optical element adjacent to the envelope and adapted to transmit light within a desired angle range and to reflect light outside of the desired range back into the envelope for recycling; an integrator adapted to receive light from the angle selector; and an angle transforming optical element adapted to receive light from the integrator. In some examples, the angle selecting optical element, the integrator, and the angle transforming optical element are all hollow and made integral with each other. In an other example, the angle selecting optical element, the integrator, and the angle transforming optical element are separate pieces utilize various mechanical features to position the pieces with respect to each other.

According to another aspect of the invention, an optical apparatus. includes a polarizer cube adapted to receive light on an input face and transmit light of a first polarity through a first output face along a first optical axis and to reflect light of the

second polarity through a second output face; a polarization rotater positioned proximate to the second output face for changing light of the second polarity to be of the same polarity as the first polarity; and a mirror for directing light from the polarization rotater to go in the same direction as the light transmitted through the first output face.

According to another aspect of the invention, an optics tube, includes a lens tube adapted to receive and secure lenses therein; a first flange connected to an input end of the lens tube, the first flange defining a structural feature adapted to mate with a corresponding feature on an aperture lamp to provide optical alignment along an optical axis; and a second flange connected to an output end of the lens tube, the second flange defining a structural adapted to mate with a corresponding feature on an enclosure, whereby the aperture lamp is held in proper alignment for providing light into the enclosure.

According to another aspect of the invention, a lamp system, includes an RF driven light source; a lens tube mounted to the RF driven light source; and an RF choke positioned between the lens tube and the light source and adapted to reduce EMI from the light source. For example. the RF choke comprises a conductive mesh screen.

According to another aspect of the invention, a lamp system, includes an enclosure having a length, a width, and a depth, wherein the depth is much less than either the length or the width; an aperture lamp positioned to direct light inside to the enclosure; and a lens system adapted to receive light from the aperture lamp and shape the light output to be more evenly distributed within the enclosure. For example, the enclosure comprises a standard 2x2 or 2x4 trough and wherein the lens system comprises a cylindrical lens positioned to reduce the angular extent of the light with in one dimension with respect to the depth.

According to another aspect of the invention, a projection system includes an electrodeless light source; an image gate illuminated by the electrodeless light source; and a shutter which is selectively opened and closed to project an image from the image gate, wherein the electrodeless light source is modulated in accordance with the opening and closing of the shutter.

The foregoing and other features and aspects of the invention are achieved individually and in combination. The invention should not be construed as requiring two or more of such features unless expressly recited in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the invention will be apparent from the following more particular description of preferred embodiments as illustrated in the accompanying drawings, in which reference characters generally refer to the same parts throughout the various views. The drawings are not necessarily to scale, the emphasis instead being placed upon illustrating the principles of the invention.

Fig. 1 is a schematic, cross sectional view of a lamp system according to the invention for performing etendue recycling.

Fig. 2 is a graph of angular distribution of light for an aperture lamp as compared to a Lambertian distribution.

Fig. 3 is a graph of intensity versus beam angle for a lamp system with unrestricted output, with restricted output and no recycling, and with restricted output utilizing etendue recycling.

Fig. 4 is a cross sectional schematic view of a lamp system according to the invention utilizing a high temperature wire grid polarizer for polarization recycling.

Fig. 5 is a cross sectional schematic view of a lamp system according to the invention utilizing both etendue recycling and polarization recycling.

Fig. 6 is a fragmented, perspective view of a first fiber optic bundle according to the invention.

Fig. 7 is a schematic, fragmented, cross sectional view of a lamp system utilizing the fiber optic bundle according to the invention.

Figs. 8A to 8D are schematic, cross sectional views of process steps for making a fiber optic bundle according to the invention.

Figs. 9A to 9D are schematic, cross sectional views of alternative process steps for making a fiber optic bundle according to the invention.

Fig. 10 is a schematic, cross sectional view of a second fiber optic bundle according to the invention.

Fig. 11 is a perspective view of a third fiber optic bundle according to the invention.

Fig. 12 is a schematic, fragmented cross sectional view of a lamp system utilizing a micro-lens array according to the invention.

Fig. 13 is a partial cross sectional view of a lamp system utilizing a chamfered aperture.

Fig. 14 is an enlarged fragmented view of the chamfered aperture from Fig. 13.

Fig. 15 is a cross sectional view of a lamp system utilizing an optical element to define the bulb aperture.

Fig. 16 is a cross sectional view of a lamp system utilizing angle selective coatings.

Fig. 17 is a schematic, cross sectional view of a remote aperture lamp system according to the invention.

Fig. 18 is a schematic, cross sectional view of another remote aperture lamp system according to the invention.

Figs. 19-24 are perspective views, respectively, of different optical elements and remote aperture configurations according to the invention.

Fig. 25 is a diagram of an optical system configured to provide a plane source of polarized light.

Fig. 26 is a cross sectional view of a lamp system utilizing the optical system from Fig. 25.

Fig. 27 is a cross sectional view of a jacketed bulb with an integral light rod.

Fig. 28 is a cross sectional view of a jacketed bulb with an integral light rod, where the bulb jacket is beveled.

Fig. 29 is a cross sectional view of an electrodeless lamp bulb with an integral lens.

Fig. 30 is a cross sectional view of an aperture lamp utilizing the bulb from Fig. 29.

Fig. 31 is a schematic view of a ball lens.

Fig. 32 is a schematic view of a molded ball lens in accordance with an aspect of the present invention.

Fig. 33 is a front schematic view of the molded ball lens.

Fig. 34 is a cross sectional view of a mold for making the molded ball lens.

Fig. 35 is a cross sectional view of an alternative mold for making the molded ball lens.

Fig. 36 is a schematic view of a molded CPC with an integral flange.

Fig. 37 is a cross sectional view of the molded CPC.

Fig. 38 is a perspective view of a molded TLP with an integral flange.

Fig. 39 is a cross sectional view of the molded TLP.

Fig. 40 is a schematic view of a tapered light cone with angled steps.

Fig. 41 is a schematic view of the tapered light cone together with a lens.

Figs. 42 - 44 are left side, front, and bottom schematic views, respectively, of a CPC.

Figs. 45 - 47 are top, front, and right side schematic views, respectively, of a truncated CPC cut along the dashed lines from Figs. 42-44.

Fig. 48 is a front view of the truncated CPC adapted with a remote aperture.

Fig. 49 is a perspective view of a segmented solid CPC.

Fig. 50 is a perspective view of a segmented hollow CPC.

Fig. 51 is a schematic view of an optical system for bending edge rays in accordance with an aspect of the invention.

Fig. 52 is a schematic view of another optical system for bending edge rays.

Fig. 53 is a cross sectional schematic view of a lamp system utilizing an etendue selection method in accordance an aspect of with the present invention.

Fig. 54 is a cross sectional view of a lamp system utilizing an angle selection method and integrator in accordance with an aspect of the present invention.

Figs. 55-59 are cross sectional schematic views, respectively, of alternative constructions of the optics from the lamp system illustrated in Fig. 54.

Fig. 60 is an enlarged view of the area 60 in Fig. 59.

Fig. 61 is a schematic diagram of a an example optical system according to an aspect of the present invention.

Fig. 62 is a schematic diagram of another example optical system according to an aspect of the present invention.

Fig. 63 is a schematic diagram of a further example optical system according to an aspect of the present invention.

Fig. 64 is a schematic diagram of a projection system according to an aspect of the invention.

Figs. 65 is a schematic diagram of a lamp system utilizing a polarizer cube in accordance with another aspect of the invention.

Figs. 66 is a schematic diagram of a lamp system utilizing a polarizer cube in accordance with another aspect of the invention.

Figs. 67 - 69 are top, left side, and right side schematic views, respectively, of an optics holder in accordance with an aspect of the present invention.

Fig. 70 is a front schematic view of an aperture bulb suitable for use with the optics holder.

Figs. 71 - 72 are left side and top schematic views, respectively, of a lens tube in accordance with an aspect of the present invention.

Fig. 73 is a schematic view of an RF screen adapted to be received by the lens tube.

Fig. 74 is an enlarged, fragmented, cross sectional view of the RF screen mounted in the tube.

Fig. 75 is a perspective view of an enclosure used for the light box of an aspect of the present invention.

Fig. 76 is a perspective view of a lens used in the light box.

Fig. 77 is a fragmented, cross sectional view of the light box.

DESCRIPTION

In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, interfaces, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the invention may be practiced in other embodiments that depart from these specific details. In certain instances, descriptions of well known devices and methods are omitted so as not to obscure the description of the present invention with unnecessary detail.

Etendue recycling

According to the present invention, an increased amount of light is delivered into a desired etendue from an aperture lamp, where the aperture lamp is described, for example, in the above-referenced PCT Publication No. WO 99/36940. In certain applications, e.g. projection systems, an important performance parameter is the number of lumens delivered to, for example, an optical imaging element with a given area and angular acceptance. in this context, etendue, ε, is defined as:

$$\varepsilon = \pi \times (\text{Area}) \times \sin^2(\theta)$$

where θ is the half angle of the cone of the specified light rays.

A three dimensional light source, such as a conventional arc lamp, utilizes an external reflector to redirect and focus the light onto the desired object or plane, with consequential losses due to collection efficiency among other factors. Moreover, an arc lamp generally provides only a localized bright spot, with a large fraction of the source lumens emanating from a different, significantly less bright portion of the discharge.

The aperture lamp of the '940 Publication addresses many of the above problems by providing a two-dimensional light source with a highly uniform light output. A ball lens may be placed in contact with the lamp aperture and suitable lenses may thereafter be employed to provide light having a desired beam angle. However, a potential for further improvements has been identified by the present inventors.

The actual light distribution from the aperture lamp is shown in Fig. 2. As shown in Fig. 2, for higher angles the light output falls off faster than the Lambertian $\cos(\theta)$ curve. A Lambertian optical distribution is of constant brightness. In other words, the brightness viewed from any angle is the same. A consequence of this is that any angular filtering of a Lambertian source yields the same brightness. Light is added or subtracted at the same rate as etendue.

For a sub-Lambertian source, however, there is less light at larger angles. The lens structures disclosed in the '940 publication incorporate these angles into the transmitted light and consequently increase etendue proportionately greater than they increase light. According to the present aspect of the invention, light outside of a desired angle is redirected back to the lamp in order to reduce the impact of sub-

Lambertian light output on etendue. According to another aspect of the invention, the size of the lamp aperture is increased such that with the constrained output angle the larger lamp aperture area matches the target etendue. Increasing the aperture size has the effect of slightly decreasing the peak forward directed brightness while significantly increasing the amount of output light. This differential can represent a substantial gain in the amount of light directed into the target etendue.

One lamp system capable of etendue recycling utilizes a ball lens having a reflective exterior surface defining an aperture. Large angle light is reflected back into the lamp, where it is reabsorbed and re-emitted with a probability given by the previous integrating sphere approach. This may result in decreased light output but will also decrease etendue. Light output may be further increased by increasing the size of the lamp aperture.

Fig. 1 is a schematic, cross sectional view of a preferred lamp system for performing etendue recycling. An aperture bulb 3 includes a bulb 5 disposed in a ceramic cup 7. The bulb 5 is positioned against a front ceramic washer 9 which defines a first aperture 11. The space interior to the cup 7 not otherwise occupied by the bulb 5 is filled with reflective ceramic material 13. A back ceramic disc 15 is positioned in the cup 7 behind the reflective material 13. Further details regarding the construction of the aperture cup 3 may be found by reference to the '940 publication.

A ball lens 17 is positioned in front of the aperture 11 and functions to reduce the beam angle of light emitted from the aperture 11. An optical element 19 is spaced from the ball lens 17 and defines a second aperture 21 corresponding to a desired angle of light to be passed, where the angle is defined with respect to the optical axis of symmetry. A reflective surface 23 of the optical element which faces the aperture 11 is configured to be direct at least some light which is outside of the desired angle back into the bulb 5 where it may be absorbed and re-emitted by the plasma. For example, a photon travelling along path A exits the ball lens 17 along path B where it encounters the optical element 19 and is returned to the bulb 5 along path C. There is a non-zero probability that some of the returned waste light will be re-emitted and exit the first aperture 11 within the desired angle to pass through the

second aperture 21, thereby increasing the intensity of the light passing through the aperture 21.

in the preferred embodiment illustrated in Fig. 1, the ball lens 17 has a first radius R1 and the optical element 19 has a second radius R2, which is larger than R1. The ball lens 17 and the optical element 19 do not share a common center. However, their respective center points C1, C2 are aligned along a common optical axis indicated by center line C_L. The optical element 19 is configured such that its center point C2 is located interior to the bulb 5 and preferably close to the aperture 11 so that most of the light reflected by the optical element 19 is transmitted through the aperture 11 and into the bulb 5.

Fig. 3 is a graph of intensity versus beam angle for a lamp system with unrestricted output, the same lamp system except with restricted output and no recycling, and the same lamp system except with restricted output utilizing etendue recycling. As is apparent from the graph, simply restricting the output (e.g. with an non-reflecting aperture stop) does not increase the intensity but only decreases the beam angle of the light. However, by utilizing etendue recycling in accordance with the present invention (e.g. with the embodiment of Fig. 1), not only is the beam angle decreased, the light intensity is significantly increased.

<u>High temperature polarization recycling</u>

As noted in the aforementioned '091 patent, light of an undesired polarity may be beneficially recycled by certain lamp plasmas such as, for example, sulfur, selenium, tellurium, indium halide, and other metal halides. Conventional optical elements for performing such recycling include optical films such as double brightness enhancement film (DBEF) made by Minnesota Mining and Manufacturing (3M). Such films are typically made of plastic and are unable to withstand high temperatures. Moreover, such films may degrade in the presence of ultraviolet light, thereby limiting the useful life of optical systems utilizing such films with broad spectrum light.

Fig. 4 is a cross sectional schematic view of a lamp system according to the invention utilizing a high temperature wire grid polarizer for polarization recycling. An aperture bulb 33 is similar to the aperture bulb 3 including a bulb 35 disposed in a ceramic cup 37. The bulb 35 is positioned against a front ceramic washer 39

which defines an aperture 41. The space interior to the cup 37 not otherwise occupied by the bulb 35 is filled with reflective ceramic material 43. A back ceramic disc 45 is positioned in the cup 37 behind the reflective material 43.

According to a present aspect of the invention, a wire grid polarizer 46 is positioned directly in front of the aperture 41. A ball lens 47 is positioned against the polarizer 46 on an opposite side of the polarizer 46 with respect to the aperture 41. The lamp system may further include an optional cleanup polarizer 49, which in Fig. 4 is disposed on the curved outer surface of the ball lens 47.

The wire grid polarizer 46 is configured to pass light of a desired polarity and to reflect light of the undesired polarity back in to the bulb 35 through the aperture 41. The returned light has a non-zero probability of being absorbed by the fill and re-emitted with the desired polarity, thereby increasing the useful light output. An advantage of the wire grid polarizer 46 is that it is made of high temperature materials (e.g. metal and glass) and is capable of withstanding high operating temperatures (e.g. at least about 400° C). Suitable wire grid polarizers are commercially available from a variety of sources including, for example, Moxtek Inc. of Orem, Utah.

Depending on the particular lamp configuration, the temperature directly in front of the aperture 41 may still be in excess of the maximum operating temperature for the polarizer 46. Under these circumstances, the polarizer 46 is omitted and the cleanup polarizer 49 is instead utilized as the primary polarizer for the lamp system. The polarizers 46 and 49 may be made integral with the ball lens 47 or may be separate pieces.

Etendue and polarization recycling

Fig. 5 is a cross sectional schematic view of a lamp system according to the invention utilizing both etendue recycling and polarization recycling. An aperture lamp 3 is as described above with respect to Fig. 1. The ball lens 17 is positioned in front of the aperture lamp 3 and an optical element 19 is spaced from the aperture lamp 3. A wire grid polarizer 51 is disposed in the second aperture 21 defined by the optical element 19.

In operation, at least some of the light which is outside of the desired angle defined by the aperture 21 is reflected back to the bulb 5 through the aperture 11

and at least some light which is within the desired angle but of an undesired polarity is also reflected to the bulb 5 through the aperture 11. Consequently, the light exiting the lamp system through the aperture 21 is both within a desired angle and of a desired polarity. Some fraction of the light returned to the bulb is recycled by the plasma and exits the lamp system within the desired angle and with the desired polarity, thereby increasing the useful light output.

Advantageously, the polarizer 51 is sufficiently spaced from the aperture bulb 3 to maintain the operating temperature of the polarizer at a suitable operating temperature, typically much less than its specified maximum operating temperature. Moreover, the materials of the wire grid polarizer 51 do not substantially degrade in the presence of UV light, and thereby do not limit the useful life of the lamp system.

A further advantage of the combination etendue / polarization recycling lamp system is that a properly configured optical element 19 together with the wire grid polarizer 51 can reduce electro-magnetic interference (EMI) leakage. Both the optical element 19 and the polarizer 51 can be made from conductive materials. For example, the optical element 19 may comprise a mirror made from silver and the wire grid polarizer 51 may comprise an array of metal wires. According to a present aspect of the invention, the optical element 19 and the polarizer 51 are incorporated in a lens tube which is also made of electrically conductive material (e.g. aluminum), all of which are electrically connected together and grounded to form an effective EMI shield.

<u>Efficient coupling of light into a fiber optic</u>

According to a present aspect of the invention, a lamp system is configured to provide more efficient coupling of light from an aperture lamp into a fiber optic bundle, where the fiber optic bundle has interstitial spaces between the individual fibers. Such interstitial space may be, for example, "dead space" due to the cladding which surrounds each fiber. In conventional lamp systems, light from the lamp striking the interstitial space is not subsequently transported in the fibers and is otherwise lost as waste light. This interstitial space can occupy from 15-40% of the fiber bundle and accordingly represents a significant loss of light.

According to the invention, this problem is overcome by depositing a reflecting layer on the interstitial areas of the accepting surface of the fiber optic

bundle, while leaving the individual fiber surfaces untouched. The light reflected from the interstitial areas is then sent back into the active lamp volume, some fraction of which is recycled and re-emitted. The re-emitted light has a non-zero probability of intercepting and entering the active fiber surfaces as light which is transported by the fibers. The reflecting interstitial spaces effectively become part of the reflecting envelope of the aperture lamp. Likewise, the sum of the individual fiber apertures then represents the effective aperture area for the lamp, and the aperture lamp is preferably configured taking this effective aperture area into account.

Fig. 6 is a fragmented, perspective view of a first fiber optic bundle according to the invention. A fiber optic bundle 61 includes a plurality of individual optical fibers 63. The individual fibers 63 define an interstitial space therebetween and a reflective material 65 is disposed over the interstitial space.

Fig. 7 is a schematic, fragmented, cross sectional view of a lamp system utilizing the fiber optic bundle according to the invention. An aperture lamp 62 includes a bulb 64 covered by a reflective ceramic 66 which defines an aperture 67. The lamp system is configured such that an end of the bundle 61 having the reflective material 65 disposed thereon is positioned proximate to the aperture 67. A photon emitted from the plasma 68 which exits the aperture along path A enters an individual fiber 63 and is transported through the fiber. A photon emitted from the plasma which exits the aperture along path B encounters the reflective material 65 and is returned to the plasma 68, where it is absorbed by the plasma 68 and re-emitted with a non-zero probability of entering one of the individual fibers 63.

Advantageously, the optical properties of the fiber optic bundle lend themselves to a variety of potential processes for depositing the reflecting layers on the interstitial spaces. One such process is described below.

Photo-active surface chemistry is well known in the art for patterned metalization. In this type of process, a thin film photo-active layer is deposited on the subject surface. The surface is then exposed to a patterned image of light which changes the chemical activity of the photo-active layer in the regions exposed to the light. The "exposed" surface is then "developed" with further chemistries to remove the initial photo-active layer in those regions which have been exposed, and to selectively deposit a thin film metallic reflecting layer in those regions which have not

been exposed. Exposing the areas covering the active fiber surface is as simple as exposing the other surface of the fiber bundle to the necessary light for photo-activating the thin film.

Figs. 8A to 8D are schematic, cross sectional views of process steps for making a fiber optic bundle according to the invention. Fig. 8A illustrates an initial fiber optic bundle 71 including a plurality of individual fibers 73 and interstitial material 74. In Fig. 8B, a photo-active adhesion layer 77 is deposited on one end of the fiber optic bundle 71 and the other end of the fiber optic bundle 71 is exposed to suitable light 79 for activating the layer 77. Only that area of the layer 77 which is coincident with the individual fibers 73 is actually exposed to the light. As shown in Fig. 8C, after further processing the remaining adhesion layer 77 corresponds to the area coincident with the interstitial area 74. Finally, as shown in Fig. 8D, a metalized reflector layer 75 is selectively deposited on the remaining adhesion layer 77.

There are a wide variety of other processes which could be used to selectively convert the interstitial areas in the fiber bundle to reflecting surfaces. The process above is additive - that is the reflecting materials are selectively added to the interstitial spaces. A selectively subtractive process could also be applied where the initial thin film is photo-actively adhered to the fiber surfaces and removed from the interstitial areas; the entire surface is subsequently coated with reflecting material which adheres well to the uncoated interstitial areas; the resulting surface is then exposed to an aggressive solvent which attacks the underlying developed photo-active material on the active fiber surfaces but which does not attack the reflecting coating on the interstitial material. This selectivity can be achieved, for instance, which an organic photo-active material and an inorganic reflective layer (which might be either metallic or dichroic).

Figs. 9A to 9D are schematic, cross sectional views of alternative process steps for making a fiber optic bundle according to the invention. In Fig. 9A, a fiber optic bundle 81 has a layer of organic material 87 which can be photo-stabilized deposited on an end surface thereof. The other end of the bundle 81 is exposed to suitable light 89 for stabilizing the material 87. As shown in Fig. 9B, after further processing the remaining material 87 is the material which is coincident with the fibers 83 while the removed material is the material coincident with the interstitial

material 84. In Fig. 9C, a directionally deposited reflector layer 85 is added to the bundle 81. In Fig. 9D, a solvent is used to selectively remove the organic layer 87 together with the reflective material 85 deposited thereon. The remaining reflective layer 85 corresponds to the reflective material which is coincident with the interstitial material 84.

Advantageously, both of the above processes utilize the geometry of the fiber bundle to provide a self-aligned selective processing of the reflective layer, thereby obviating the need for additional photo-masks and simplifying the manufacturing process.

Color recycling

Fig. 10 is a schematic, cross sectional view of a second fiber optic bundle according to the invention. According to a present aspect of the invention, the reflective material in the interstitial spaces is combined with selective wavelength reflection to recycle even more light. In Fig. 10, a fiber optic bundle 91 includes individual optical fibers 93 and interstitial material 94. One end of the bundle 91 further includes a completely reflective layer 95 which is coincident with the interstitial material 94 and a selectively reflective layer 97, which is at least coincident with the fibers 93 and in Fig. 10 covers the entire surface of that end of the bundle 91. For example, the selectively reflective material 97 may comprise a red / green / blue (RGB) band pass dichroic material. In operation, light which strikes the reflective layer 95 is reflected back to the bulb and light which is outside of the desired wavelengths and strikes the reflective layer 97 is selectively reflected back to the bulb for recycling. Depending on processing considerations, the order of the selectively reflective layer 97 and the reflective layer 95 may be reversed (e.g. the dichroic material may be on top of the metal material).

Alternatively, three separate bundles could be used to selectively extract separate color bands (e.g. one each for red, green, and blue) simultaneously from three respective apertures of the same lamp, while the non-used light is recycled from each aperture. Three separate fibers or fiber bundles would be coated with dichroic bandpass filters for the three desired RGB bands. The light reflected from each bandpass filter would immediately be recycled because the filter would be in close proximity to the aperture lamp.

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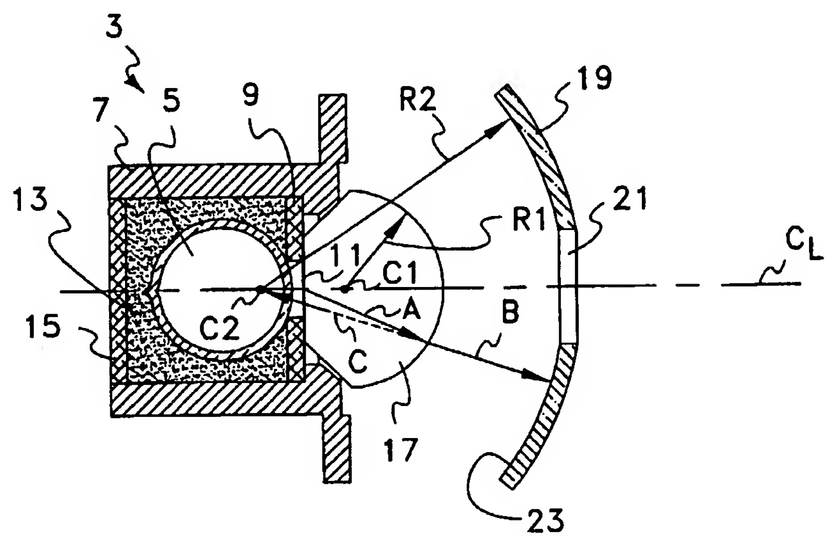
[Continued on next page]

(54) Title: LAMP APPARATUS AND METHOD FOR EFFECTIVELY UTILIZING LIGHT FROM AN APERTURE LAMP



(57) Abstract: Various lamp systems are disclosed which effectively utilize light from an aperture lamp (3). Lamp systems are respectively configured to perform various types of light recapture including etendue recycling, polarization recycling, and/or color recycling. Various novel optical elements are disclosed including an electrodeless light bulb (5) with an integral lens (9), a molded quartz ball lens with an integral flange, a molded quartz CPC with an integral flange, a truncated CPC, and a segmented CPC. Various novel optical systems are disclosed including systems which perform angle selection and/or etendue selection.

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NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ------- Y -------- A	US 5,903,091 A (MacLennan et al.) 11 May 1999 (11.05.99), entire document	1, 11, 13, 14, 16, 32, 33 --------- 2, 3, 4, 8, 36 ---------- 5, 15, 17, 18,21,23,
Y	US 4,688,897 A (GRINBERG et al.) 25 August 1987 (25.08.87), enitre document	2, 3, 4
X ------- Y	US 5,953,477 A (WACH et al.) 14 September 1999 (14.09.99) enitre document	6, 7 ------- 8

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	US 4,757,427 A (OOSTVOGELS et al.) 12 July 1988 (12.07.88), entire document	12
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X	US 5,434,664 A (SAPP) 18 July 1995 (18.07.95), col. 4, line 37 through column 5, line 3	22
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